Fire Spread Over Pitched Roofs Fitted with Solar Panels

Experimental Update

Prepared by researchers at the
Health and Safety Executive

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1 Introduction

1.1 Research Aim

The aim of this work is to study how the installation of photovoltaic (PV) panels affects the fire spread over pitched roofs in residential buildings. To achieve this a series of eleven large scale experiments have been carried out at HSE's Science and Research Centre. This work has been commissioned by the Technical Policy team within the Building Safety Regulator (BSR) and aims to assist them in determining if further guidance is required in Volume 1 of Approved Document B (ADB) [1]. This is the statutory guidance document published by the UK Government under the Building Regulations 2010, specifically addressing fire safety in buildings in England.

Previous incidents [2] and experiments [3-4] have suggested that the installation of PV panels may increase fire spread over a roof. The BSR was concerned that this could cause fire spread to adjacent buildings, over fire compartment lines and potentially into the building itself through elements such as skylights. This project was set up to determine what design elements increase fire spread over the roof and to record data on these types of fires.

1.2 Purpose

This experiment update report provides an summary of initial findings from experimental testing which has been completed. This document has been produced to share initial findings of this work ahead of the publication of the full report.

To achieve this, the information within this report is based on observations made by those conducting the tests and some limited findings from the initial interpretation of the data. The full report for this work has not yet been produced, and data interpretation and validation are not fully complete for all tests, therefore this report is issued with the caveat that **findings may evolve as the final report is produced.**

2 Experimental Setup

The standard used to classify the fire performance of roofs in ADB is BS EN 13501-5 [5] and the test standard used within this is test four in CEN/TS 1187 [6]. The TS 1187 standard test was developed to assess generic roof types. As such, incorporating PV panels into the test arrangement creates issues. For example, its limited size makes it difficult to fit a full PV panel on the test sample. The experimental setup used on this project aimed to scale up some elements of TS 1187 to a more realistic scale, so that flame spread could be studied in both the horizontal and vertical directions. Some elements of the standard were deemed impractical to achieve at a larger scale, such as the negative pressure applied to the sample. Instead, to simulate a wind flow over the roof an array of fans was positioned at the front of the sample to produce an average windspeed of 6.7 m/s over the sample.

All experiments carried out studied the fire spread over a two-by-two PV array mounted on a pitched roof with an angle of 45°. This angle was chosen as this was assumed to represent the worst case scenario on common construction in terms of fire spread, also in the test standard [6], results obtained at a pitch of 45° apply to all roofs with pitches >10°. To achieve this angle a custom frame was fabricated shown in Figure 1. All samples were built on this frame above a base layer of a combustible oriented strand board (OSB) deck. The remainder of the roof was then constructed above this consisting of: membrane, roofing battens and roof tiles. PV Panels were either integrated into the roof construction or supported above the roof tiles creating a void space under the panels. Other variables altered throughout the series of eleven samples included: the material of the roof tiles, the IEC fire classification of the PV panels themselves (IEC 61730-2 [7]), the reaction to fire classification of the roofing membrane (BS EN 13501-1 [8]) as well as multiple different types of integrated systems being tested.

A fire risk created by the addition of PV panels to a roof, unlike most other roof materials, is they can act as an ignition source themselves. In particular the current test standard does not test for an ignition source in the cavity beneath the PV panel, a small cavity such as this can cause greatly increased fire spread. A common example of an ignition source in this area is a failure of DC-DC connectors [9-10], commonly caused through material incompatibility or incorrect installation. This work replicated a DC-DC connector failure by using a wooden crib as the ignition source underneath the PV panel.

Figure 2 shows an example of one of the complete samples. Visible on this image is the wooden ignition crib which was specifically designed for this work and constructed of an arrangement of square 21 mm pine battens to give an overall dimensions of 400 x 400 x 63 mm.

This ignition crib was positioned underneath the bottom left solar panel in the array, where the DC-DC connections would be made. For the above roof tests this was above the roofing tiles but for the integrated systems this meant the crib was in contact with more combustible elements of the roof.

Each experiment was monitored by thermocouples and visual observation to track the flame spread over the sample. Radiometers were positioned at the side and top of the sample to measure the heat flux which could be applied to adjacent buildings or building elements such as skylights. Also, the mass loss of the sample was measured during the fire using load cells positioned under each foot of the support frame. All data was collected to our internal quality and calibration standards and will be included in the final report.

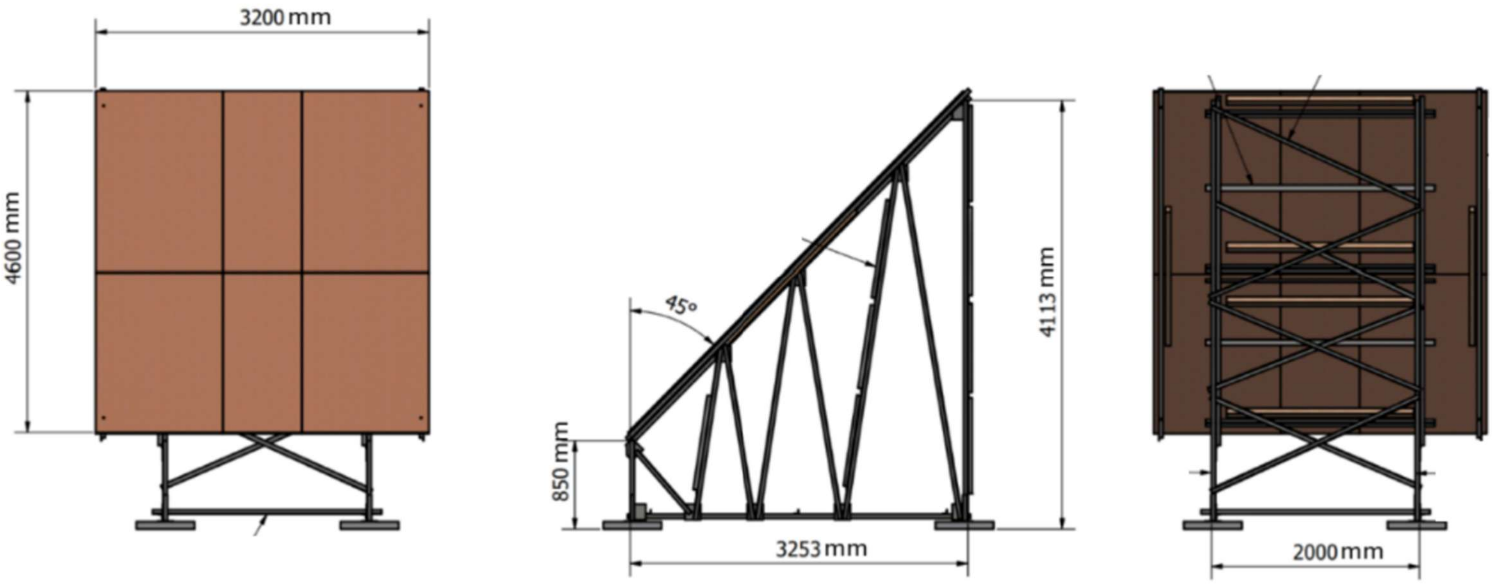

Figure 1 – Technical drawing of the support frame on which the samples were constructed.

Figure 2 – Image of sample 4 showing an example of the experimental setup. The ignition crib is highlighted in red.

3 Results

3.1 Building Applied Photovoltaic (BAPV) Panels

A BAPV panel system is one where the solar panels are fixed above the roof tiles. To achieve this the panels are mounted to rails which are secured to the roof by brackets fixed below the tiled roof. This creates a void space between the panels and the roof panels.

BAPV panel systems tested included samples 2–5. Further details of each sample are given in Table 1 and details of the results are given in sections 3.1.1 - 3.1.5. These experimental runs compared the fire spread for different back sheet foil materials of the solar panels themselves and the type of roof tiles used.

Sample No.	Description of Sample	IEC Fire Classification of PV panels (IEC 61730-2 [9])	Roofing Material (Reaction to fire classification BS EN 13501-5[5])
1	Control test of ignition crib fixed to the roof of concrete roof tiles, without any solar panels in place.	N/A	Concrete roof tiles [BROOF(t4)]
2	Plastic backed solar panels with class C fire rating (**Manufacturer A**), fixed above a roof of concrete roof tiles.	C	Concrete roof tiles [BROOF(t4)]
3	Plastic backed solar panels with class C fire rating (**Manufacturer B**), fixed above a roof of concrete roof tiles.	C	Concrete roof tiles [BROOF(t4)]
4	Plastic backed solar panels with class C fire rating (Manufacturer A), fixed above a roof of plastic roof tiles.	C	**Plastic** roof tiles [BROOF(t4)]
5	Glass backed solar panels (bifacial) with class A fire rating (Manufacturer A), fixed above a roof of concrete roof tiles.	**A**	Concrete roof tiles [BROOF(t4)]

Table 1 – Details of tests with PV panels fixed above the roof tiles.

3.1.1 Sample 1 - Control

Sample 1, the control test, showed very limited flame spread, with no materials other than the wooden ignition crib involved in the fire.

3.1.2 Sample 2 – Plastic backed PV panels (Manufacturer A)

During this test there was significant vertical fire spread up the array reaching the top of the panels, but the fire did not spread significantly horizontally. The fuel which allowed for this fire spread was the plastic backing of the panel. After testing, it was observed that the majority of this material had been burned on the bottom left solar panel above the crib and some of the top left solar panel had also been involved in the fire. This allowed for flames to extend to the top of the solar panel array however the plastic had only been fully burned to approximately half of the way up this top panel. The involvement of the panel can be seen in Figure 3.

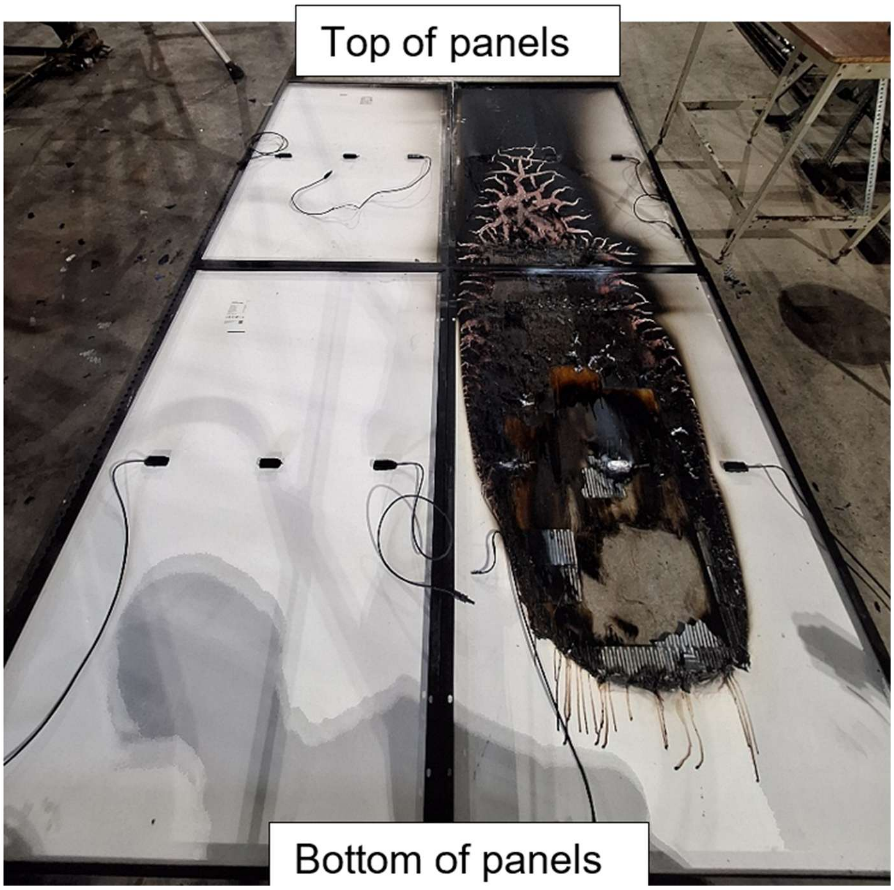

Figure 3 – Post test image of the back the solar panels. Left hand PV panels displayed on the right as the panels have been flipped.

3.1.3 Sample 3 - Plastic backed PV panels (Manufacturer B)

The only variable in this test which was changed from sample 2 is the solar panels installed above the roof. The PV panels installed on this sample were the same IEC 61730-2 [9] fire classification (Class C) and have a plastic backing material but were an alternative product sourced from a different manufacturer. This test was carried out to determine if different panels with the same stated fire performance perform differently. It was observed that the panels in this test performed the same as those on sample 2 with very little difference in fire spread.

3.1.4 Sample 4 – Plastic backed PV panels, Plastic roof tiles

For this sample plastic roof tiles were used instead of the interlocking concrete roof tiles used on all other tests, the plastic backed (class C) PV panels from Manufacturer A were installed above this. A system using these roof tiles has achieved a fire classification of BROOF(t4), according to BS EN 13501-5 [5]. During this test there was significant fire spread both vertically and horizontally. Almost all of the roof tiles below the solar panels very rapidly became involved in the fire and this greatly increased the fire spread over the sample when compared to samples 2 and 3.

Approximately 2 minutes after the fans were turned on (4 minutes into the test) the flames had reached the top of the roof. The fire then spread horizontally until almost all of the tiles under the solar panels were involved in the fire (except for half of the bottom right-hand panel). The fire was extinguished after just over 8 minutes due to safety concerns. During this experiment the roof tiles provided a very significant fire load and caused a large plume of flame to extend significantly past the top of the roof, as can be seen in Figure 4. This produced the largest heat flux recorded in any of the tests. However, the flames did not extend a significant distance horizontally past the PV panels.

Figure 4 – Sample 4 at the peak of the fire, approximately 8 minutes.

3.1.5 Sample 5 – Bifacial PV panels, Concrete roof tiles

The test set up was identical to samples 2 and 3 other than the PV panels used were bifacial (e.g. glass backed not plastic backed). As such they had a higher fire performance of Class A. Fire spread was much less significant on the bifacial panels (class A) when compared to samples 2 and 3. The materials of the panel did however eventually contribute to the fire in the area directly above the ignition crib. During the test the lower glass surface of the panel began to distort in the area directly above the wooden crib. Eventually this shattered and the materials in the centre of the panel provided fuel for the fire. The fire did not spread significantly beyond this point and did not extend to involve the rest of the solar panel or spread to any other panels in the array, as can be seen in Figure 5.

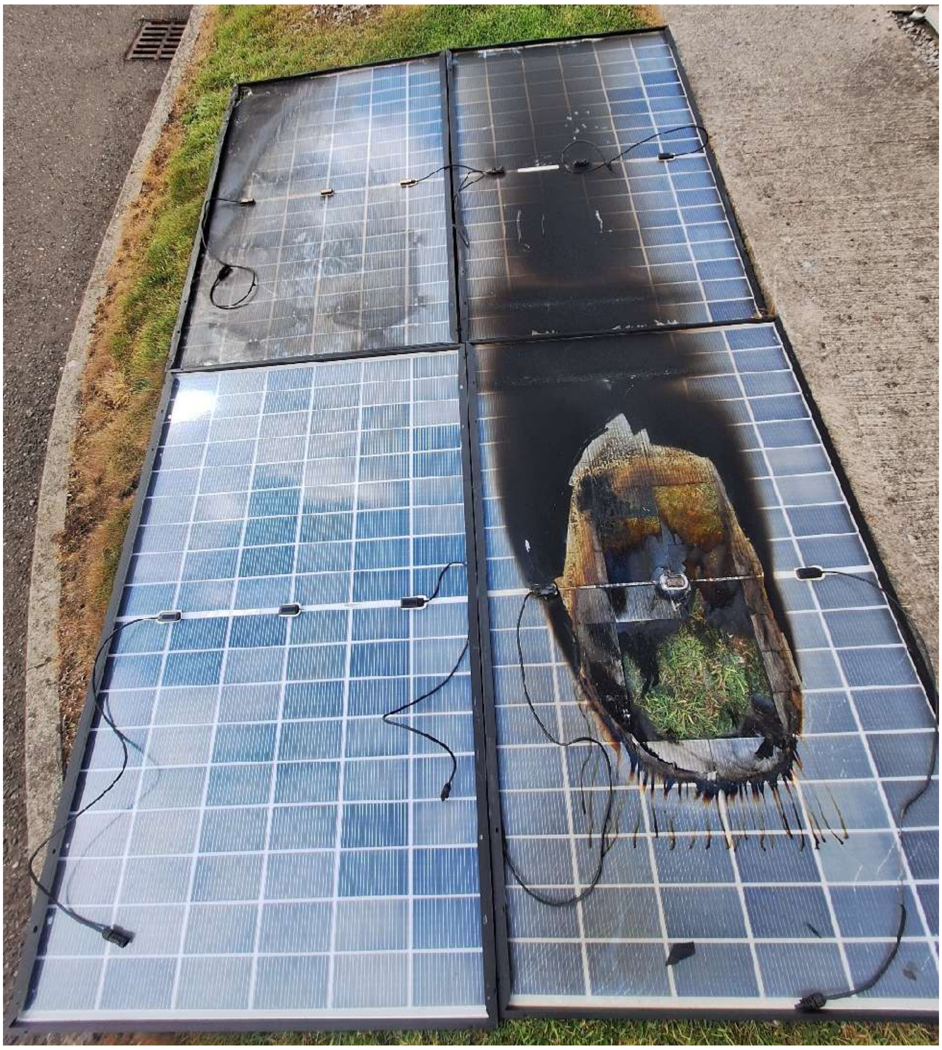

Figure 5 - Post test image of the back the solar panels. Left hand PV panels displayed on the right as the panels have been flipped.

3.2 Building Integrated Photovoltaic (BIPV) Panels

Here, a BIPV panel system is defined as a system where the solar panels act as the watertight layer of the roof, with the solar panel flush to or close to being flush with the tiles on the rest of the roof. Standard interlocking concrete roof tiles were used around the edges of all of the BIPV tests, as they would be installed in line with the manufacturer's instructions.

In total, three types of integrated system were tested. These included two plastic tray systems from the same manufacturer, which are designed to fit standard solar panels. One test was also carried out of a bespoke integrated system (sample 11) where the flashing details fasten directly into the PV module. Additionally, the effect of the breather membrane was studied; samples 6,7 and 8 had the same set up but used breather membranes with different reaction to fire performances.

In each of these tests the ignition crib was directly exposed to combustible materials due to the positioning of the crib below the solar panels, this included roofing battens on all tests and plastic trays on samples 6-10.

Sample No.	Description of Sample	IEC Fire Classification of PV Panels (IEC 61730-2 [9])	Type of Integrated System
6	Type 1 plastic tray integrated system, class E breather membrane	C	Type 1 plastic tray system
7	Type 1 plastic tray integrated system, class B breather membrane	C	Type 1 plastic tray system
8	Type 1 plastic tray integrated system, class A2 breather membrane	C	Type 1 plastic tray system
9	Type 1 plastic tray integrated system, class E breather membrane	**A**	Type 1 plastic tray system
10	**Type 2** plastic tray integrated system, class E breather membrane	C	**Type 2** plastic tray system
11	Bespoke integrated system, class E breather membrane	-	Bespoke integrated system with aluminium flashing details connecting directly into the PV modules

Table 2 – Details of tests with PV panels integrated into the roof.

3.2.1 Samples 6, 7 & 8 - Type 1 plastic tray systems with different breather membranes

The variable tested in samples 6, 7, and 8 was the reaction to fire performance of the breather membrane. This ranged from the lowest performance Class E in sample 6 to the highest performance Class A2 in sample 8. All the tests of the plastic tray systems with plastic backed PV panels performed similarly. There was flame spread to the top of the roof within approximately 7 minutes and significant horizontal flame spread underneath the right-hand solar panels. The reaction to fire classification of the breather membrane did not have a significant effect on the flame spread. For all of these experiments, the flames reached the top of the roof in around 7 minutes. Figure 6 shows the flame spread on sample 8 approximately 15 minutes into the fire.

Figure 6 – Sample 8, 15 minutes into the fire.

3.2.2 Sample 9 – Type 1 plastic tray system, Bifacial solar panels (Class A)

Sample 9 was identical to sample 6 other than the PV panel was a Class A glass backed (Bifacial) panel compared to the plastic backed Class C panel used in sample 6. The vertical flame spread was slower on this sample when compared to the tests with plastic backed PV panels, as the flames reached the top of the roof within 15 minutes, after which the fire continued to spread horizontally.

3.2.3 Sample 10 – Type 2 plastic tray system

The variable changed from sample 6 in this test was the type of plastic tray system used to mount the solar panel. The tray used on this sample was similar to those used in samples 6-9 but had a different geometry and included less plastic.

There appeared to be little difference between the two types of plastic tray system. In sample 10 the flames reached the top of the roof in 7 minutes, the same as in samples 6-8. The fires also showed similar horizontal flame spread to the right-hand panels.

3.2.4 Sample 11 – Bespoke integrated system

The flame spread during this test extended over a smaller area and was slower during this test when compared to the plastic tray systems (samples 6-10). The fire was confined to the cavity and the flames did not extend beyond the top of the PV panels. During the 17 minute duration of the test, the flames did however reach the top of the upper solar panel in this cavity. The reduced flame spread is due to a smaller amount of fuel in the cavity, when compared to samples 6-10, since there is a smaller mass of wooden support battens in this area when following the manufacturers installation instructions and no plastic trays. Also, the cavity was somewhat restricted by the frames of the PV panels. The peak of the fire (approximately 15 minutes after ignition) visible from the front is shown in Figure 7.

Figure 7 - Sample 11, approximately 15 minutes into the fire.

4 Discussion and Summary

4.1 Building Applied Photovoltaic (BAPV) Panels

The series of experiments showed that on plastic backed PV panels (class C, IEC 61730-2 [9]) there was significant vertical fire spread up the array reaching the top of the panels, but the fire did not spread significantly horizontally, and the fire did not pass between the panels in this direction. Fire spread was much less significant on the glass backed panels (class A, IEC 61730-2 [9]) and it did not extend past the first PV panel. Although the panel materials did become involved the fire, the flames did not extend significantly from the area around the ignition crib.

One experiment was carried out above plastic roof tiles which achieved a classification of BROOF(t4), when classified in BS EN 13501-5 [5] (without PV panels installed). Flame spread on this sample was much greater than all other tests in this work with the entire area under the solar panels rapidly becoming involved in the fire and large flames produced above the top of the roof.

One variable which was observed to be relevant in this series of experiments is the position of the support rails on the roof systems. Along the aluminium edge material surrounding the PV panels these mounting rails appeared to slow the spread of the fire up the rear surface of the panel. It was observed that they caused the fire to be forced down away from the rear surface of the panel and so acted as a fire break.

4.2 Building Integrated Photovoltaic (BIPV) Panels

In these samples the significant amount of wooden support battens and the plastic trays provided a large fuel source for the fire. Significant vertical and horizontal flame spread was observed in all of the plastic tray integrated systems with flames extending above the top of the roof. The bespoke integrated system showed less vertical flame spread however, we believe this to be due to there being less fuel available in the cavity below the panels.

It was observed that these fires were significantly harder to extinguish than the above roof systems. Part of the fire was contained in the cavity behind the waterproof layer of the roof fully sealed by the solar panels and flashing, meaning it was harder to apply water to this area unless the fire had burnt an opening in these materials. This finding is highlighted as it may be relevant to the fire service when attending these incidents.

4.3 Summary

In summary, all samples which incorporated PV panels had greater flame spread than the control sample. Even where the PV panel provided limited fuel to the fire (as in sample 5), the cavity created by the solar panel allowed the flames to reach higher up the sample.

For the BAPV samples above concrete roof tiles there was significant vertical flame spread but very limited flame spread horizontally to the adjacent PV panel. The back material of the glass backed panels contributed less to the fire than the plastic backed panels which provided a thermally thin layer of fuel for the fire. The plastic roof tiles used on sample 4 showed very rapid flame spread and quickly allowed for other roof materials to become involved in the fire that was not expected, given their high fire classification in BS EN 13501-5 [5].

When compared to BAPV systems, with the exception of sample 4 (plastic roof tile sample), the BIPV samples showed greater fire spread both horizontally and vertically, although there were some differences between flame spread on the different types of integrated system. All the integrated systems involved other roof elements in the fire including the roof battens, breather membrane and plastic support trays (excluding sample 11) and they all had to be extinguished early on safety grounds. In contrast, the BAPV systems burned out themselves after the ignition crib died down and the available combustible material on the back sheet of the PV panel was consumed. Additionally, it is noted that the BIPV fires were often difficult to extinguish as the fire was protected from water in the cavity created by the panels/flashing.

Following the completion of this series of tests an additional four tests have been commissioned. These included one test of the plastic roof tiles used on sample 4, without the PV panels fitted. This will allow comparison of how much the solar panels effect the flame spread over these roof tiles. Additionally, the significant flame spread and involvement of other roofing materials in the fire on the BIPV samples has identified that fire penetration into building may warrant further investigation. The three other tests will study the penetration of a fire on BIPV systems further. These will be constructed on a more representative roof construction i.e. the system will be built above roof rafters, instead of the OSB deck used in all other tests. The three different tests will study the penetration of the fire into the building and how effective fire retardant breather membranes are at preventing this, breather membranes of three different reaction to fire classifications (Class E, B and A2) will be used.

5 References

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